State of Louisiana
Department of Natural Resources
Coastal Restoration Division

Monitoring Plan

for

Terrebonne Bay Shore Protection Demonstration

State Project Number TE-45
Priority Project List 10

September, 2005
Terrebonne Parish

Prepared by:

Todd Folse, Monitoring Section (CRD)
LDNR/Coastal Restoration and Management

MONITORING PLAN

PROJECT NO. TE-45
TERREBONNE BAY SHORE PROTECTION DEMONSTRATION PROJECT

ORIGINAL DATE: September 12, 2005

Project Description

The Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) of 1990 (PL 101-646, Title III) included the Terrebonne Bay Shore Protection Project (TE-45) as part of the 10^{th} Priority Project List authorized on January 10, 2001. The TE-45 project is located southeast of Chauvin, Louisiana in Terrebonne Parish along the rapidly eroding northwest shore of Lake Barre, which is part of the Terrebonne Basin system (Figure 1). The project will evaluate six fabricated structures, placed along the shore, for their effectiveness in abating shoreline erosion including their ability to develop and sustain an oyster reef. The project examined five potential shoreline reaches during the engineering and design phase with the purpose of selecting three (3) reaches for the demonstration project based on several criteria (Hebert 2002); reaches A, B and E (Figure 1) were selected. The project's monitoring life is eight (8) years post-construction.

In Louisiana, coastal land loss has been estimated at approximately 25 square miles (64.7 square kilometers) $year^{-1}$ (Dunbar et al. 1992) to 35 square miles (90.6 square kilometers) $year^{-1}$ (Barras et al. 1994). More specifically, the average shoreline erosion rate for the five proposed reaches along the north shore of Lake Barre are 4.95 feet (1.51 meters) $year^{-1}$ for the period of 1932 to 1983 (May and Britsch 1987). Due to high rates of erosion along the north shore and salinities conducive for oysters, this project location was chosen to evaluate the effectiveness of the six different structure types including the oyster's ability to provide additional protection.

The eastern oyster, *Crassostrea virginica* (Gmelin), is the dominant reef-building estuarine organism along the northern Gulf of Mexico. Because of Louisiana's climate, it has the ability to spawn almost year round, but usually exhibits bimodal peaks of mass spawning in spring-early summer and again in early-late fall (Butler 1954). When waters are warm in summer, planktonic larvae require less than two weeks to metamorphose through several life stages before they are ready for settlement and a benthic life (Galtsoff 1964). Newly settled oysters often experience high mortalities in the first six months of life (Roegner and Mann 1995). At the time of setting, oyster larvae are usually less than 0.5mm in size, and are very vulnerable to predation and to burial due to sediment overburden. A hard substrate that provides refuge from predators and provides vertical relief from sediments is of significant importance to assure a chance for survival. Once the larva has set, it will become known as a "spat oyster" until it is 25mm (1 inch) in shell length. The juvenile stage is short-lived with oysters maturing with functioning gonads within 4-12 weeks of settlement in summer water temperatures (Menzel 1951). Young oysters grow rapidly and can reach 75mm (3 inches) in shell length within 12-15 months in Louisiana waters. After an oyster is approximately 8 years old, somatic tissue growth

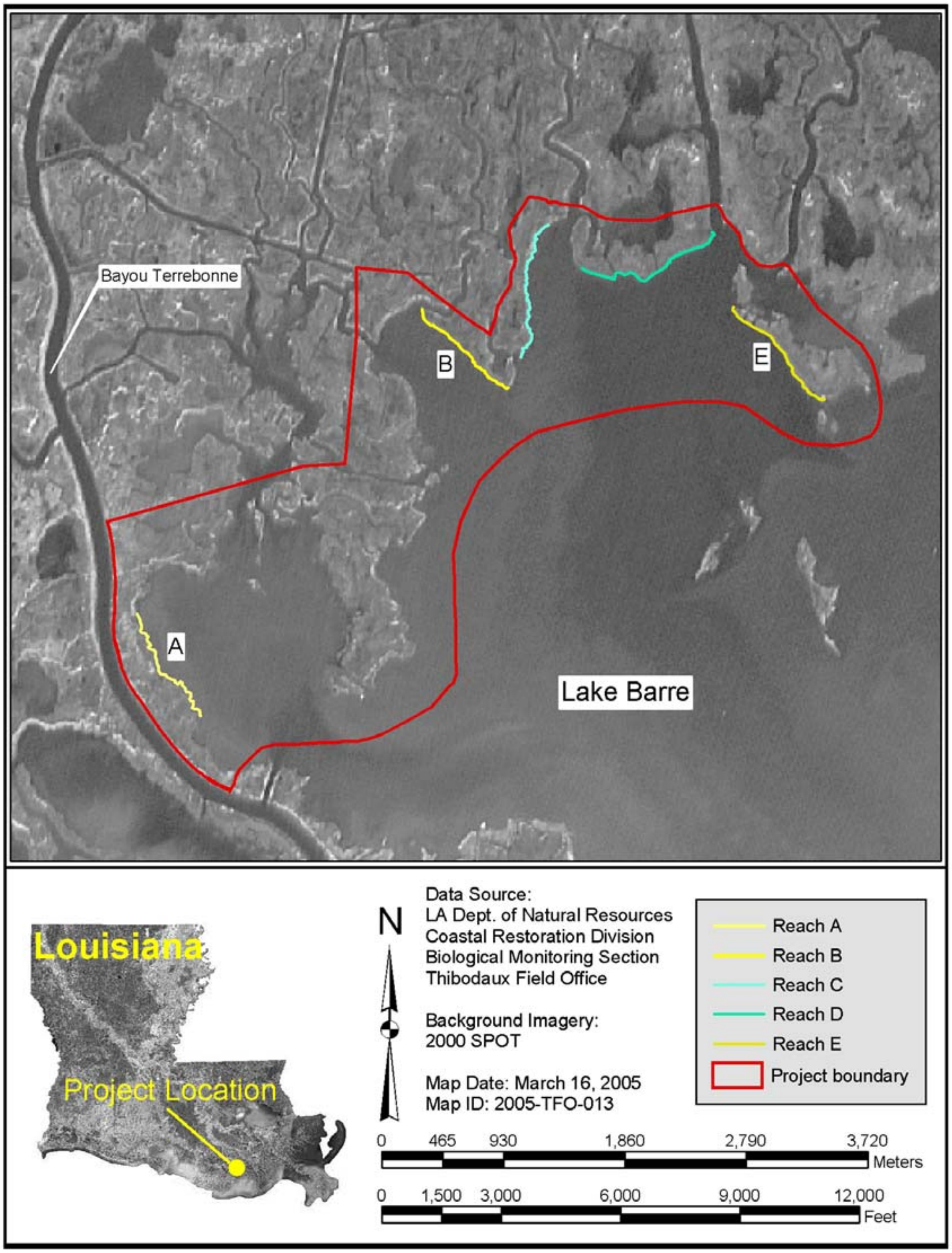

Figure 1: Project location map with the delineated shoreline reaches investigated and selected for protection.

is insignificant or ceases and the volume of the mantle/shell cavity remains relatively constant (Cake 1983). Oysters in the northern Gulf of Mexico may live for 10 years. Two terms that originates from the commercial industry to describe oysters, but are often used in the scientific community, are “seed oyster” (25-75mm in shell length) and “sack oyster” (>75mm in shell length).

The oyster occurs in salinities ranging from 5-40ppt (Shumway 1996). Optimal growth and survival of commercially viable oyster populations require a salinity range of 5-15ppt, when coupled with an appropriate temperature regime. This narrow ecological salinity range reduces the abundance of higher-salinity oyster predators and disease while still allowing for physiological functions to continue. When other environmental variables are within acceptable ranges for oyster survival, salinity becomes the overriding factor for sustaining an oyster population (Dekshenieks et al. 2000). Melancon et al. (1998) delineated resource zones where oysters can be found under persistent drought (dry) or rainy (wet) conditions within the Terrebonne estuary. Four zones were established, with a mid-bay region referred to as the wet-dry zone where oysters can be found irrespective of wet or dry conditions, and allowing for both subtidal and intertidal oyster habitats. This mid region of the estuary is where the majority of naturally productive commercial oyster leases exist today. The location of this project is within the wet-dry zone.

The location, distribution and physical dimensions of an oyster population depend on many interacting factors which include complex associations of physical, chemical, geological and biological processes (Kennedy et al. 1996). Environmental and biological variables such as predation and disease, food quality and quantity, suitable bottom substrate, adequate tidal flushing, water currents, temperature, salinity, and an array of other variables interact to produce a habitat capable of developing and sustaining an oyster population. For example, Bahr and Lanier (1981), while describing intertidal reefs along the South Atlantic coast, identified important driving forces for oyster survival and reef development to be predation and competition, water current regime, particulate organic matter (food), tidal amplitude, and extreme air temperatures. Bartol et al. (1999), working with intertidal oysters in the Piankatank River of the Chesapeake Bay system, demonstrated the importance of vertical relief and depth of substrate in providing critical intertidal-subtidal zonation and refuge for oyster survival. Working with subtidal oysters in the Galveston Bay estuary, Powell et al. (1994) and Dekshenieks et al. (2000) developed mathematical models to interpret rates of oyster mortality and population crashes using the forcing functions of salinity, water flow rate, food availability (chlorophyll-a and total suspended solids), turbidity, and water temperature. While also working with subtidal oysters, Lenihan (1999) demonstrated that shape of a reef influences water flow and becomes a critical variable to settlement and reef development success. Understanding the environmental variables that provide the necessary infrastructure for an oyster population to survive is fundamental to this project’s ability to interpret success or failure of reef development.

The oyster is a gregarious animal that has the ability to develop shallow subtidal and intertidal reef structure that also adds significant ecological value to an estuary. An oyster reef is a 3-dimensional structure created by successive years of larval settlement on adult oysters, while also providing multiple levels of hard surface and interstitial heterogeneity that is rare in the marine ecosystem (Bartol et al. 1999). The oyster becomes the keystone organisms for a multitude of invertebrate and vertebrate species in a dynamic estuarine community (Coen et al. 1999), that includes many recreational and commercial species (Zimmerman et al. 1989).

Louisiana's interior bay shorelines are experiencing high rates of erosion and marsh loss. There is significant dual benefit in abating bay shoreline erosion with the use of fabricated structures that also have the ability to establish oyster populations. Oyster populations can continuously respond to changing environmental conditions such as salinity, subsidence and sea level rise with continuous reef growth. For example, Meyer et al. (1997) demonstrated the effectiveness of oyster cultch (shell) to marsh edge stabilization and sediment accumulation, while Gagliano et al. (1997) pointed out that fabricated vertical structure placed along an eroding marsh shoreline has significant erosion-control and oyster habitat-developing potential.

<u>Project Goals and Strategies/Coast 2050 Strategies Addressed</u>

Project goals and strategies are provided to the Louisiana Department of Natural Resource's Coastal Restoration Division (LDNR/CRD) through the Environmental Assessment (EA) compiled by the federal sponsor, the U.S. Department of Interior's U.S. Fish and Wildlife Service (USFWS). The USFWS stated in 2003 the following goals and strategies:

Project Goals:

1. To reduce shoreline erosion while minimizing scouring to the bay bottom adjacent to each shoreline protection treatment.

2. To quantify and compare the ability of each of the shoreline protection treatments to reduce erosion and enhance oyster production.

3. To quantify and compare the cost-effectiveness of each shoreline protection treatment in reducing shoreline erosion and enhancing oyster production.

Project Strategies:

1. To use diverse shoreline protection treatments to reduce erosion within the project boundary.

2. To select shoreline protection treatments which will provide habitat for oyster spat adhesion and growth.

3. To generate a sound experimental design that will allow for statistical testing and evaluation of the project goals.

Project Features

During the feasibility and preliminary design phase of the project, six shoreline protection structures and five artificial oyster reef structures were reviewed before selecting the six structures that would be constructed for this project (Hebert 2002). The six fabricated structures (treatments) include three placed onshore, a Submar™ pre-cast articulating concrete mattress, a Triton™ gabion concrete mat filled with rock or shell, and an A-Jack™ Concrete Barrier with an underlying support layer of geotextile fabric and crushed rock; and three placed foreshore, a concrete Reef Ball™, a metal-framed Reef Block™ filled with rock or shell, and a prefabricated Concrete Frame designed by Mr. Brian Kendricks, P.E.

A treatment, along with a control (reference) stretch with no structure, will be 91.4 meters (300ft) in length to establish a contiguous distance of 640 meters (2,100ft) per shoreline. The cumulative distance of all treatments equals 1,920 meters (6,300ft; 1.2 miles), and the total number of individual units equals 3,634 (Table 1). Due to the experimental design of the project, all six treatments and the reference area will be placed at each of the three selected shoreline reaches; therefore, each treatment is replicated three times. Treatments are randomly selected to determine the order in which they would be constructed at each shoreline reach. The results of the selection process are shown in Table 2.

Table 1. Type and potential number of fabricated erosion-control structures placed at the three shoreline sites in CWPPRA Project No. TE-45.

MATERIALS USED IN PROJECT	Experimental Material's Width per Unit (ft)	Number of Units Needed per 300 ft of Shoreline(1)	Number of Rows of Materials on or adjacent to a Shoreline	Number of Shoreline Reaches	Total Number of Units Within all 3 Shoreline Reaches
Shoreline Protection Treatments:					
Submar™ Pre-cast Articulating Concrete Mattress	8	38	1	3	114
Triton™ Gabion Mats Filled with Rock or Shell	5	60	1	3	180
A-Jack™ Concrete Barrier	2	653	1	3	1960
Foreshore Protection Treatments:					
Reef Balls™ (concrete)	2.5	360	3	3	1080
Reef Blocks™	5	60	1	3	180
Prefabricated Concreted Frame	7.5	40	1	3	120
Reference Shoreline Site (no treatments): 300 feet at each reach					
TOTAL					3,634
Potential Cumulative Distance of Shoreline at the Three Sites = 1.2 Miles					

Table 2: Order of randomly selected treatments to be placed along each of the three shoreline reaches beginning at the 0+00 survey transect of each reach established during the preliminary design survey.

Reach A	Reach B	Reach E
Reefblock	Reefball	Concrete A-Frame
A-Jacks	Reference	Reefball
Concrete A-Frame	Submar Mat	A-Jacks
Submar Mat	Concrete A-Frame	Reefblock
Reefball	Reefblock	Submar Mat
Gabion Mats	A-Jacks	Gabion Mats
Reference	Gabion Mats	Reference

Monitoring Goal

CWPPRA demonstration projects are designed to statistically and scientifically determine alternative restoration techniques by using multiple methods at smaller scales but having multiple replicates. Demonstration projects have smaller budgets and a shorter project life (typically 5-8 years) to determine which method or methods being demonstrated have the maximum potential to positively impact the areas in which they were designed to protect, yet must be constructed and designed for a longer lifespan (20 years) to adequately demonstrate effectiveness.

The monitoring goal for the TE-45 project is to determine the effectiveness and differences in the 6 treatments for reducing shoreline erosion including the developing oyster reefs. The technique or techniques that show the greatest positive potential for achieving the project goals and objects may be utilized in a large-scale restoration effort typically design for the CWPPRA process.

Priorities:

Once oyster colonization and reef development are detected using underwater camera and video documentation, a treatment will be sampled quantitatively. To determine whether a treatment or reference area has developed and sustained an oyster reef, a density of 25 oysters per square meter will be used as the threshold. This density follows Cake (1983) which suggests a density of 25 oysters per square meter is a well-established population.

Estuaries are highly variable and therefore require an adequate sampling regime to address the scale of the research question being asked (Livingston 1987). Coupling an estuary's inherent nature for heterogeneity with the inherent clustering nature of oysters generates a significant challenge to adequately develop a sampling regime. The sampling regime must accurately portray how each structure type is performing in reef development. Therefore, the method of assessment must be multi-layered, where each layer of sampling strategy adds further insight for final interpretation. The following sampling elements and protocol will initially satisfy that need, but must remain flexible enough to change as observations and data are generated, and as long as statistical integrity is retained.

Specific Monitoring Goals

1. To evaluate the effectiveness of each shoreline protection treatment's ability to reduce erosion by conducting topographic/bathymetric surveys around each treatment.

2. To determine the effectiveness of each shoreline protection treatment's ability for oyster reef development and distribution.

3. To compare cost-effectiveness of each shoreline protection treatment and to use this information to determine if one or more of the experimental treatments is better at developing and sustaining an oyster reef.

4. To evaluate the integrity of each treatment type by conducting surveys that will provide data concerning shifting and settlement along with inspections performed by departmental engineers.

Reference Area

Due to the design of the project, one reference area has been incorporated into the layout of each shoreline reach. These three areas are 91.4 meters (300 ft) in length and are randomly placed within each shoreline reach will represent the shoreline as if there were no protection along the reach. This area will enable erosion rates to be calculated based on no protection.

Monitoring Strategies

Temperature and salinity are the major environmental parameters that govern oyster physiology, oyster predator and disease levels, and water stratification in the bay. Also documenting dissolved oxygen levels can become critically important during high summer temperatures, when significant algal blooms occur, and when salinity may rise and produces water stratification. Tidal height (water elevation) is another critical parameter to measure with respect to the upper tidal limit of reef development. Tidal flow also has a significant influence on how food availability and metabolic waste removal are cycled within an oyster reef, and also influences the availability of dissolved oxygen. The following monitoring strategies delineate the variables and survey schedule for data collection.

1. Topographic Survey

   To determine erosion, progradation, accretion, and/or scouring, professional surveyors will survey a minimum of three transect lines per treatment within 150ft from the center. Three transects will be established through each treatment and reference area. Transects will be established 75 feet from each terminal end of the treatment and one in the center. Surveys will begin on the marsh surface approximately 50 feet from the shoreline and extend approximately 100 feet past the farthest treatment. Elevations will be collected at a maximum of every 10 feet, at the vegetated shoreline, at the toe of the shoreline, at significant breaks in elevation, at the front toe of the treatment at the mud line, at the top of the treatment, at the back toe of the treatment, and along the bay surface for approximately 100 feet past the treatment. Surveys will be conducted in the years 2005 (As-built), 2007, 2009, and 2012.

2. Continuous Water Temperature and Salinity Monitoring

   One continuous recorder will be located at each of the three reaches near the middle (A, B, E; Figure 1). This continuous recorder will collect hourly readings of water temperature, specific conductance, and salinity. After two years of data collection, the data will be analyzed for any correlations or differences between the instruments. If it is determined that the data from all three instruments do not show statistical differences (strongly correlated), then a decision may be made to remove one or two continuous recorders. Consequently, only one or two instruments may be deployed for the duration of the project.

   In addition to the three continuous recorder instruments, small portable disc-type temperature recorders capable of collecting hourly water temperature will be deployed at different water depths on a PVC pole. These recorders will allow for a vertical profiling of the water temperature, which is essential to document differences among the subtidal and intertidal zones. Intertidal exposure to extreme heat or cold could influence oyster survival and influence reef formation. One (1) PVC pole will be established at each of the three shoreline sites. The small discs are inexpensive and can be retrieved for downloading to a computer and replaced with new ones when necessary.

   Monthly discrete sampling will occur at the ends and middle of each treatment transect and where the structures have any internal void spaces. The discrete samples will be collected with a hand-held instrument capable of collecting an array of parameters for the duration of the project.

3. Continuous Water Elevation (tidal height) Monitoring

   To determine the depth and duration of the treatments and marsh flooding, water elevation will be collected on an hourly basis using the continuous recorders at each of the three shoreline sites described above. Duration of daily submersion influences oyster setting, survival, growth and spawning, predator abundance, and the extent of structure fouling. To insure the accuracy of the daily submersion data determined from these stations, these recorders will be surveyed by professional surveyors at the beginning of the project and at each shoreline survey sampling years. The surveys will be adjusted to the South Louisiana GPS Survey Network using the same benchmark as treatment construction. Again, correlations of recorders will be analyzed, and a determination will be made if recorders can be reduced. Consequently, only one or two instruments may be deployed for the duration of the project.

4. Discrete Water Temperature, Salinity, Turbidity, pH, Dissolved Oxygen (D.O.), and Percent Dissolved Oxygen saturation (% D.O.) Monitoring

    Monthly discrete sampling will occur with respect to water temperature, salinity, turbidity, pH, D.O., and % D.O. saturation. These parameters will be collected using a multi-parameter instrument. Sampling will occur at the ends and middle of each treatment. For those treatments that have internal spaces, sampling will occur within the treatments since dissolved oxygen is an important parameter especially during the summer months. Data collection will begin once the project is constructed and continue for the duration of the project.

5. Discrete Chlorophyll-a and Total Dissolved Solids Monitoring

    Water samples will be collected on a monthly basis and returned to the laboratory at Nicholls State University. These samples will be analyzed for chlorophyll-a (ug/l) and total dissolved solids (ug/l). These two variables will characterize the available food needed for oyster growth and development. Data collection will begin once the project is constructed and continue for the duration of the project.

6. Discrete Water Current Monitoring (tidal flow rate around fabricated structures)

    A single-point FlowTracker Doppler flow meter attached to an aluminum pole and positioned adjacent to or in each type of experimental treatment will be used to collect discrete tidal flow rate measurements. A Doppler flow meter produces greater accuracy and can also be used in very shallow water. A secondary method will employ multiple 75 mm (3-inch) diameter chlorine tablets placed within structures to track dissolution rate similar to the methods used by Bartol et al. (1999). This will provide an index of water flow across and through the treatments over an extended time period of hours. Each treatment has a unique design and will influence water movement in its own way, especially those with internal spaces. The two methods give a reasonable measure of water flow, but do not give an index of how oscillatory flow and turbulence intensity influences measurements. Data collection will begin once the project is constructed and will occur during the months of May through August of each year for the duration of the project.

7. Oyster Colonization and Density

    Oyster settlement and biofouling on each experimental treatment will be documented systematically using a portable SeaViewer model SeaDrop underwater video camera that will interface with a camcorder and a Trimble GPS unit capable of sub-meter accuracy. The underwater video camera is very versatile and can be mounted on an aluminum pole or held by a diver and maneuvered around a treatment with topside images captured by a camcorder, or a laptop computer.

This video camera allows for relatively rapid inspection while also quantifying the percentage of area colonized. Each structure will be marked into a grid that will take into account a treatment's shape, location (onshore or foreshore), windward or leeward side, height (supratidal, intertidal, or subtidal), and internal spaces for potential oyster refuge. Oyster colonization within a grid will be assigned values as follows: 0=no oysters present, 1=1-25% coverage, 2=26-50% coverage, 3=51-75% coverage, and 4=greater than 75% coverage. Although this method does not directly measure density in terms of number per square meter, a 26% coverage per treatment type will be considered as the threshold for establishing an oyster reef.

Louisiana's estuarine waters are not noted for their clarity, therefore the video camera is designed to function with low light in murky conditions. In addition, a digital camera will be used when treatments are exposed at lowest tides, again mostly in winter or during a wind event when water is pushed out of the bay. Data collection with the video camera will take place in December of each year once the project is constructed and continue for the duration of the project.

Ten (10) units of each treatment type will be randomly selected and inspect every area within. When a treatment begins to develop significant colonization of oysters, then it will be revisited annually throughout the study to document reef development progress. We will document experimental treatments and controls at a minimum annually through years 1-8.

Once visual colonization is established, quantitative density samples will be taken on representative treatments. A density of 25 oysters per square meter is considered an established reef (Cake 1983). Oyster density ($\#/m^2$) is a major dependent and continuous variable in any statistical analyses for treatment (structure type) assessment of its reef-building potential. Samples will be acquired once per year, preferably in the month of July, once the video camera data indicates an oyster presence during the December data collection period.

8. Oyster Population Size Frequency Analysis

On an annual basis oysters will be collected for size frequency analyses from colonized treatments. Oyster samples will be collected by randomly removing at minimum a 2-liter bucket full of oysters from each treatment type. Measuring the length of each oyster's shell to the nearest millimeter and then classifying in 5mm and 25mm categories will develop size-frequency histograms. Oysters will be assigned as live, recently dead (no or limited biofouling inside shell) or older dead.

Samples will be collected during the summer of each year after the May spawn. Size Frequency analysis documents colonization success, year classes and survival.

This above method allows for the ability to generate quantitative population data while covering approximately 1.2 miles (~2Km) of shoreline with over 1,400 experimental treatments. It also allows for the ability to take into account a treatment's unique shape, size, and ability to provide oyster refuge. Oyster collection for population size frequency will begin one complete year after construction has been completed allowing for the settlement and growth of the oyster. Sample collection will be in July/August of each year once oyster establishment has occurred.

9. Oyster Recruitment

At each of the three shoreline reaches, three subtidal trays of oyster shells and three intertidal trays of oyster shells will be deployed before the spring and fall, each year after construction, mass spawning events and retrieve a month later. Oysters will be quantified as number per shell.

This is an index of oyster recruitment on natural substrate to be used for a quantitative comparison to treatments. It also establishes oyster habitat suitability of each shoreline reach independent of experimental structures (treatments).

Since this is a demonstration project that utilizes several structure types that are each unique in size, shape, and configuration, the only common characteristic is the linear distance of 91.4 meters (300 ft) along the shoreline. Another factor that dictates the monitoring design is that the treatments will be constructed sequentially; therefore, the monitoring strategies will be assessed on the central 45.7 meters (150 ft) of shoreline protected by the corresponding treatment type to eliminate as much interaction between adjoining treatments as possible.

Many units of the same type will be linked together and constitute one treatment. A unit will be further divided into subtidal or intertidal. Each subtidal or intertidal zone could be further divided into front (windward face) and back (leeward face). In the case of ReefBalls, which will be three rows deep, one can further divided into a front row, middle row, and back row. For example, 50 ReefBall rows are found within a 150ft length of shoreline and constitutes 1 shoreline treatment. A row can be divided into a front, middle and back because there are 3 balls that make up a row. A Reefball can be divided into four quadrants. It can also be divided into subtidal and intertidal. Consequently, monitoring will occur in the subtidal and intertidal zone and on all sides of an individual structure to determine where the growths of oysters are occurring.

Anticipated Statistical Analyses and Hypotheses

The following hypotheses with respect to the monitoring parameters will be used to evaluate the accomplishment of the project goals. Hypotheses dealing with the oyster reef development or oyster populations are based on the density of 25 oysters per square meter as stated by Cake (1983).

1. The primary method of analysis for shoreline change will be to determine differences in mean erosion rates as evaluated by an analysis of variance (ANOVA) that will consider both spatial and temporal variations and their interactions. Multiple comparisons will be used to compare individual means across different treatments. All original data will be analyzed and transformed (if necessary) to meet to the assumption of ANOVA (e.g. normality, equality of variances). When the H_o is rejected, the possibility of negative effects will be examined. P-values for each test will be generated and statistical significance will be assessed at the 0.05 level of significance.

   H_o: Mean shoreline erosion rate at treatment site *x* at time *I* *is* not significantly lower than the mean shoreline erosion rate at the reference shoreline *y* at time *I*.

   H_a: Mean shoreline erosion rate at treatment *x* at time *I* is significantly lower than the mean shoreline erosion rate at the reference shoreline at time *I*.

   - If H_o is accepted, then treatment *x* is capable of reducing erosion.

   H_o: Mean shoreline erosion rate at treatments *x* at time *I* is not significantly lower than the mean shoreline erosion rate at any other treatment *y* at time *I*.

   H_a: Mean shoreline erosion rate at treatments *x* at time *I* is significantly lower than the mean shoreline erosion rate at any other treatment *y* at time *I*.

   - If H_o is accepted, then one of the treatments is the most effective treatment for reducing erosion.

   A secondary method of shoreline change analysis will use a modeling software package such as the ArcView® Tin Model. This will allow maps, graphs, and charts to be produced using the survey data showing where elevations have changed in relation to the structures.

2. Survey data, observational data, and engineering operations and maintenance reports will be used to interpret structural integrity to determine which treatment(s) need(s) the least amount of maintenance. In the interpretation, an account of the actual cost per treatment will be taken into consideration to

determine which structure(s) is the best low-cost alternative to reduce shoreline erosion.

3. To determine if the six erosion-control structure types (treatments) can support the development and sustainability of oyster populations.

   H_o: There is no significant difference between erosion-control treatments in ability to establish an oyster reef.
   H_a: There is a significant difference between erosion-control treatments in ability to establish an oyster reef.

   - If H_o is accepted, then this indicates that either all treatments are effective in establishing oyster reef development, or none are effective.
   - If H_a is chosen, then we will test individual treatments to determine which is most effective in establishing an oyster reef.

4. To determine if a treatment's vertical relief (height) has an influence on oyster population and density, i.e., influence of intertidal exposure.

   H_o: There is no significant difference between subtidal and intertidal location on a treatment's ability to establish an oyster reef.
   H_a: There is significant difference between subtidal and intertidal location on a treatment's ability to establish an oyster reef.

   - If H_o is accepted, then this indicates that either both intertidal and subtidal treatments are effective in promoting oyster reef development, or neither is effective.
   - If H_a is chosen, then we will test individual treatments to determine which is most effective in subtidal to intertidal reef development.

5. To determine if water quality between shorelines reaches A, B and E is conducive to reef formation.

   H_o: There is no significant difference between shoreline reaches in individual water quality parameters.
   H_a: There is significant difference between shoreline reaches in individual water quality parameters.

   - If H_o is accepted, then this indicates that water quality are similar at all three shoreline reaches.
   - If H_a is accepted, then this indicates that water quality is significantly different and we will test for where differences exist.

6. To determine if oyster recruitment between shorelines reaches A, B and E is conducive to oyster reef establishment.

H_o: There is no significant difference between shoreline reaches in oyster recruitment
H_a: There is significant difference between shoreline reaches in oyster recruitment.

- If H_o is accepted, then this indicates that recruitments are similar at all three shoreline reaches.
- If H_a is accepted, then this indicates that recruitments are significantly different and we will test for where differences exist.

Notes:

1. Proposed Implementation:

		Start Construction	October 2005
		End Construction	December 2005
2.	USFWS Point of Contact:	Robert Dubois	(337) 291-3100
3.	DNR Project Manager:	Ralph Libersat	(225) 342-1952
	DNR Monitoring Manager:	Todd Folse	(985) 447-0991

4. Data associated with monitoring elements 2-9 will be collected through a contract with Dr. Earl Melancon at Nicholls State University (985-448-4689; earl.Melancon@nicholls.edu).

Literature Cited

Bahr, L. M. and W. P. Lanier. 1981. The ecology of intertidal oyster reefs of the South Atlantic coast: a community profile. U.S.F.W.S., Office of Biological Serv., Washington D.C. FWS/OBS-81/15, 105pp.

Bartol, I.K., R. Mann and M. Luckenbach. 1999. Growth and mortality of oysters (Crassostrea virginica) on constructed intertidal reefs: effects of tidal height and substrate level. J. Exp. Mar. Biol. Ecol., 237:157-184.

Butler, P.A. 1954. Summary of our knowledge of the oyster in the Gulf of Mexico. U.S. Fish Wildl. Serv. Bull. No. 89.

Cake, E. W., Jr. 1983. Habitat suitability index models: Gulf of Mexico American oyster. U.S. Dept. Int. Fish Wildl. Serv., FWS/OBS-82/10.57, 37pp.

Coen, L.D., M.W. Luckenback, D.L. Breitburg. 1999. The role of oyster reefs as essential fish habitat: a review of current knowledge and some new perspectives. Am. Fish. Soc. Symp. 22:438-454.

Dekshenieks, M. M., E. E. Hofmann and E. N. Powell. 2000. Quantifying the effects of environmental changes on an oyster population: A model study. Estuaries, 23(5):593-610.

Galtsoff, P.S. 1964. The American oyster *Crassostrea virginica* Gmelin. U.S. Fish Wildl. Serv, Bull. No. 64.

Gagliano, M.H., S.M. Gagliano and P.J. Moses. 1997. Bay Rambo Oyster Reef: An artificial oyster reef in the deltaic estuarine area of Louisiana. Coastal Environments, Inc. Baton Rouge, LA., 30pp.

Kennedy, V. S., R. I. E. Newell and A. F. Eble (eds.), 1996. The eastern oyster *Crassostrea virginica.* Univeersity of Maryland Press. 1,089pp

Lenihan, H.S. 1999. Physical-biological coupling on oyster reefs: how habitat structure influences individual performance. Ecol. Monogr. 69:251-275.

Hebert, Inc. 2002. Terrebonne Bay Shore Protection Demonstration Project (TE-45): Feasibility and Preliminary Design Report. LDNR Contract No. 2503-00-28. Louisiana Department of Natural Resources Coastal Restoration Division.

Melancon, E. J, T. M. Soniat, V. Cheramie, R. J. Dugas, J. Barras and M. LaGarde. 1998. Oyster resource zones of the Barataria and Terrebonne estuaries of Louisiana. J. Shellfish Res., 17(4):1143-1148.

Menzel, R.W. 1951. Early sexual development and growth of the American oyster in Louisiana waters. Science. 113:719-720.

Meyer, D.L., E.C. Townsend, G.W. Thayer. 1997. Stabilization and erosion control value of oyster cultch for intertidal marsh. Restoration Ecology 5(1):93-99

Powell, E. N., E. E. Hofmann, J. M. Klinck and S. M. Ray. 1994. Modeling oyster populations IV: Rates of mortality, population crashes and management. Fisheries Bulletin 92:347-373.

Roegner, G.C. and R. Mann. 1995. Early recuitment and growth of the American oysters with respect to tidal Zonation and season. Mar. Ecol. Prog. Ser. 117:91-101.

Shumway, S. E. 1996. Natural environmental factors. *In* V. S. Kennedy, R. I. E. Newell and A. F. Eble (eds.), The eastern oyster *Crassostrea virginica*, p.467-513.

Zimmerman, R., Minello, T.J., Baumer T. and M. Castiglione. 1989. Oyster reef as habitat for estuarine macrofauna. NOAA Technical Memorandum NMFS-SEFC-249.